Towards the Application of Pumped-Hydro Storage in Nigeria

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Abstract

Acute electricity crisis characterised by epileptic and inadequate supply remains a major hindrance to achieving sustainable development in Nigeria. The problems of poor electricity generation, transmission, and distribution have led to a slowdown of industrialisation. The effect of this is evident in the poor standard of living for the majority of the population and the poor state of the economy. While there have been concerted efforts at improving the power sector, pumped-hydro storage consideration and applicability as a potential solution has received scant attention in Nigeria. Meanwhile, its application in electricity networks merits reflection considering the present state of Nigeria electricity. This study seeks to propose the application of P-HS in Nigeria and the steps needed to support its adoption. The attempt thus raised a number of questions. Such as, what are the possible factors that are slowing the application of P-HS? What are the needed steps to accelerate the P-HS application in Nigeria? What are the specific ways in which P-HS can be applied to solve the country's electricity problem? Thereafter, a conceptual framework to describe our thought was presented and the implications of adopting P-HS in Nigeria were discussed. These include energy storage, generation and ancillary services.

Keywords
Electricity, Pumped-Hydro Storage, Nigeria, Power Sector.

1. Introduction
Energy is one of the most basic requirements for the development of a nation. Its importance in social, economic, health, education, communication and industrialisation can never be undermined (Owusu and Asumadu-Sarkodie 2016; Aized et al. 2018). Indirectly, energy influences the growth of the gross domestic product (GDP) of a nation (Narayan et al. 2010; World Bank 2019). According to Oyedepo (2012), an adequate and reliable access to energy is the engine fuel to drive the monumental growth and achieve a sustainable development. Thus, energy availability and accessibility are vital for a nation's sustenance.

However, energy in Nigeria has been grossly inadequate. The performance of the power sector in Nigeria which is responsible for providing electricity for the citizens has been very low (Adhekpukoli 2018). The low performance of the sector has contributed to a low standard of living as well as slow economic and industrialisation growth in the country. While lot of factors have led to the present predicament of electricity in Nigeria, the over-riding challenges are inadequate generation, distribution difficulty and lack of access to the electricity grid (Adaramola et al. 2012; Ogunmodimu and Okoroigwe 2018). As at 2017, Okafor (2017) and Sambo (2018) reported that out of 7102MW generation capacity (with reference to 23 Feb, 2017), the peak generation was about 4602.4MW. That is, even the installed generation plants which are yet to be adequate for the Nigeria population are not operating optimally. Aside from the insufficient electricity generation, accessibility to electricity remains at about 45% (IEA 2015; WEC 2018; Bamisile et al. 2020). World Bank (2014) data revealed that Nigeria has a low electricity per capita consumption among other Africa countries. Such as, South Africa, Botswana, Zimbabwe, Namibia with electricity per capita consumption in South Africa estimated at 4500kwh while Nigeria was about 125 kWh (Oyedepo 2012).

While the government is making efforts to redeem the situation, a huge gap still exists between the available electricity and the demand in Nigeria. Some of the efforts have included the utilisation of renewable energy sources alongside the existing non-renewable energy plants. For example, in July 2016, an agreement between the Nigerian Government and about 14 solar developers (Obideyi 2017; Detail Commercial Solicitors 2018) was reached to develop electricity generation for some areas. Also, the unbundling of power sector which was targeted at bringing in more private investors and the introduction of eligible customer model to encourage direct access between end users and generation companies (GenCos) are some of the government's effort.

2. Problem Statement

Nigeria's interest to increase electricity supply and accessibility merits the adoption of solar and wind energy sources in geographical locations with abundant resources. However, the major drawbacks of this two energy sources are intermittency and dispatch ability as their resources appear to be unevenly distributed across Nigeria. As a result, it is difficult for solar or wind to solely satisfy daily energy demand. Thus it limits their dependability without a storage system and, quest for power grid integration. For these reasons, battery storage systems are mostly applied.

However, the competitive advantage of using batteries in most solar and wind powers are limited. This owes to the fact that batteries are expensive, have short life times and may not be suitable for a large scale of solar and wind power generation (Chen et al. 2013; Kabir et al. 2018). Therefore, an effective storage system such as pumped-hydro storage is required to complement the growing interest of solar and wind power in Nigeria. Thus, this study seeks for the potential applications of P-HS and necessary steps to aid its adoption in Nigeria.

3. Pumped-Hydro Storage (P-HS) Technologies

Pumped-Hydro energy storage (PHES) is an energy storage technique that has garnered renewed interest in recent times (Aburub et al. 2019; Javed et al. 2020). It is a mechanical storage and of hydroelectric power generation type which has been in existence for more than a century (Ayodele and Ogunjuyigbe 2015). According to Rehman et al. (2015), P-HS existence can be traced back to 1890s in the Alpine regions of Switzerland, Austria and Italy. It is considered an old and more matured storage technology compared to other storages (Evans et al. 2012; Rehman et al. 2015). Such as, the compressed air energy storage (CAES), battery energy storage systems (BESS) and the flywheel energy storage (FES). P-HS has a long term storage, large energy storage capacity (Deane et al. 2010) and has been applied in the energy value chain for rapid spinning, frequency and area control, load levelling, load shifting, peak shaving, arbitrage etc. (Uddin et al. 2018; Adebimpe and Oladokun 2019).

To operate P-HS, the potential energy of water is utilised to store electricity. It has two basic operations namely; pumping and generating mode. The pumping mode, regarded as charging mode is the movement of water from the lower reservoir to the upper reservoir which are separated by a height (Adebimpe and Oladokun, 2020). While in the generating mode, water is allowed to fall through hydro turbine to generate power.

The energy for the charging operation in Pumped-hydro storage system can come from solar and wind power energy sources in Nigeria. In this case, the charging operation would be performed during the period of abundance of the respective renewable energy source (RES) and when the period of the abundance is off, the P-HS is put into full operation (Nikolaidis and Poullikkas, 2017). Figure 1 further describes the operation and the components of P-HS.

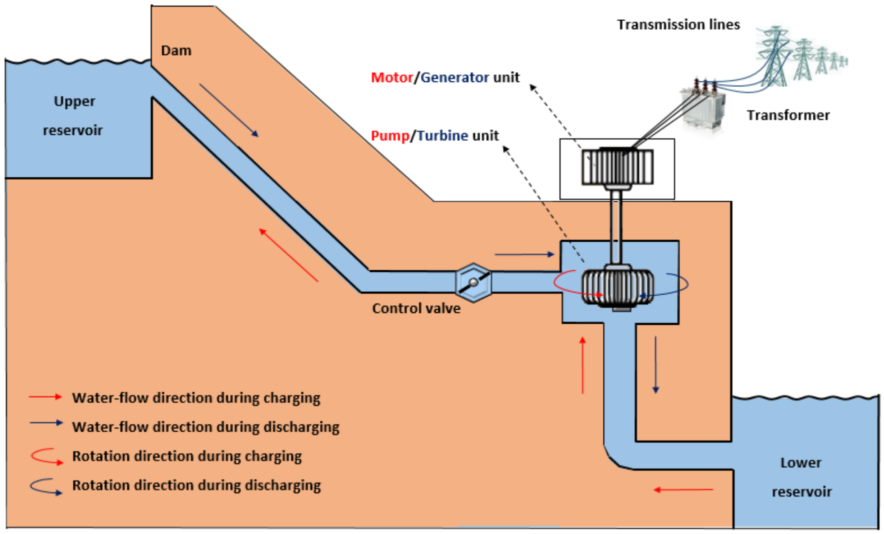

Figure 1: Diagram Describing Pumped-Hydro Storage Technology
Source: (Nikolaidis & Poullikkas, 2017)

4. Limiting Factors for the Application of Pumped-Hydro Storage in Nigeria

Although P-HS technology has been in existence for decades, its application in Nigeria still appears to be at a conceptualisation state as there is yet to be a reference point on the matter. Also, there is limited information on the application of P-HS and/or adaptation of its technology in the Nigeria electricity scenario. This dearth of information could have been one of the reasons why the stakeholders are yet to view from the P-HS technological perspective. In that light, we identified environmental factors, social factors, technical factors, economic factors and institutional factors as possible factors that are slowing down the application of P-HS technology in Nigeria.

4.1 Environmental Factors

P-HS technology largely depends on physical environment, and geographical related features for its operation. Factors such as locations with hills, mountains, valleys and large volume of water are some of the basic requirements in developing P-HS (Wu et al. 2017 and 2019). However, locating a site which has an adequate mix of these basic requirements to support P-HS is always a major challenge and thus requires a lot of survey.

Though the country is blessed with much potential such as large volume of water in mountainous and hilly areas which support the development of P-HS, these are yet to be identified across the nation. Also, the feasibility of sites for the purpose of P-HS development is yet to be given consideration in many of the documents presented on feasible sources of energy generation in Nigeria. That is, a proper identification of potential sites across the country is still lacking. Meanwhile, this kind of feasibility exists for other energy sources such as biogas, hydropower etc. in the documents of National Renewable Energy and Energy Efficiency Policy which was approved by the Federal Executive Council of Nigeria (Ministry of Power 2015).

4.2 Social Factors

Nigeria is a multi-ethnic group with different languages, cultural values and beliefs. While there are strengths in diversity, it has led to serious challenges in the past and has made decisions in the area of infrastructural development a very sensitive issue. For instance, the areas with hills and mountains serve as gods and refuge for some of the inhabitants within the area. There are people who believe in and worship Mountains. There are others who seek spiritual comfort in places with large volumes of water. An attempt to make use of these resources for P-HS may lead to friction between the inhabitants of such areas and the developer.

Similarly rivers and lakes remain a source of livelihood that has been passed from one generation to another and serve purposes such as fishing, irrigation, farming, grazing and pastures. Historically, these people have occupied areas of land and have claimed the resources culturally. Thus, they tend to resist any development that may threaten these resources.

Another challenge is the issue of satisfying all social groups through infrastructure distribution across all the geopolitical zones that exists within the country. Due to the sensitivity of the diversity issue, the common practice by the government is to attempt to satisfy every ethnic group so that none would feel marginalised. However, resources for developing P-HS are natural resources which are not evenly distributed across all the land area of the country. For instance, towards the south are large rivers, hills and mountains while towards the north east are majorly plain lands. The implication of this is that, some geographical areas have more potential for P-HS development than the other.

4.3 Technical Factors

P-HS may not be relatively new in the advance world, however, it appears to be a new concept in Nigeria as the existence of such system is limited. Therefore, to appreciate and accelerate its adoption in Nigeria, there is need for a framework to aid its deployment. This includes a generic system sizing model with capability to evaluate the system given the parameters of any potential sites and the adaptation of dig well and or storey building or the overhead tanks for P-HS at individual residences. Within the framework, provision must be made for a bidirectional power flow and synchronisation of P-HS to the grid. Currently, such model appears to be lacking in the Nigerian context. This has negatively impacted the adoption of P-HS technology in Nigeria. By making available this requisite framework in Nigeria, noticeable strengths and weaknesses of the Nigerian energy value chain can be well captured.

4.4 Economic Factors

Currently, information on the economics of P-HS in Nigeria is limited as there is yet to be a sufficient demonstration of the economic viability of the system in Nigeria. For example, the average lifecycle costs and levelised costs of storage for case studies are not known. Also, the economic comparative advantage of P-HS with battery storage, compressed air energy storage and flywheels etc. requires some analysis. Majority of the economic analysis that are readily available represents the case studies in advance countries and do not totally reflect the Nigerian energy market. Furthermore, they are too specific and do not capture some peculiarities in Nigeria. Some of such peculiarities include the socioeconomic effects of the resources to be used for P-HS, the alternative cost of the resources and the probable penalty cost. These are critical costs issues that are yet to be treated.

4.5 Institutional Factors

In Nigeria, the Federal Government remains a major player in developing major energy infrastructures. Although the energy sector was unbundled with the Federal Government now holding on to transmission alone, the private investors in the electricity sector are yet to demonstrate capacity to adequately change the narrative of the Nigerian electricity situation. To allow for the penetration of more private investors into the energy system, the backing of the government at various levels is required. In this regard, the Nigerian government has not been very active both in terms of funding and policy support.

5. Conceptual Framework

The basic steps required to aid the application of P-HS in Nigeria is presented as a conceptual framework in Figure 2. In the Figure, there are three main themes; site feasibility, techno-economic framework and energy plans and policies. With reference to Figure 1, the three themes were observed to be fundamental to the application of P-HS in Nigeria and thus we refer to it as the pillars of support towards P-HS adoption. The overlapping circle that exists between two themes (site feasibility and techno-economic framework) describes the interaction and the arrows demonstrate flow of the proposed steps towards the application of P-HS in Nigeria.

Site feasibility is a key theme of the framework. Site feasibility is an important step towards the actualisation of P-HS development. Based on the nature of the technology, an appreciable height, water and reservoir are the required basic elements in a proposed P-HS site (Rehman et al. 2015). Although, it is possible to make these elements available artificially, the technical complexity and the cost could over-burden the project and cause a reduction in its market competitiveness. In this regard, a site with appreciable height such as hills, mountains, natural reservoirs (i.e. dams, rivers etc.), and adequate volumes of water is most preferred. These form the set of criteria to be considered in this activity. Other factors to be considered under the feasibility studies include the social and environmental factors. That is, the influence of proposed P-HS development on the social and/or economic activities within the proposed area. Also, the environmental, social benefit and cost has to be properly analysed with respect to the occupants of that area. Some of the social factors that are critical for site feasibility in Nigeria contexts include freedom from violence, communal clashes, agitations and terrorist attacks as a means of reducing P-HS investment risks.

Another important aspect towards the application of P-HS is techno-economic framework to aid in the technological and economic assessment of P-HS in a proposed site. Such framework requires the consideration of some interacting factors of the site feasibility studies, the technological concept and economic principles. This is because P-HS like other renewable energy sources is influenced by both site and electro-mechanical components (Guney and Tepe 2017). For this reason, a system sizing methodology for appropriate evaluation is very much required. Thus, to develop an effective techno-economic framework, the energy demand of the scheme must be considered for energy balancing (energy supply meeting demand). In cases where the energy demand is not known with certainty, an estimated energy generation can be used as a guide.

Within the techno-economic framework is the consideration of the system mode of operation. In this sub-activity, decisions on the source of energy to integrate with the P-HS are to be made. For example, is the proposed system to be connected to power grid, existing renewable energy sources or to specifically build an integrated P-HS and renewable energy system? Also, decisions on the utilization of the stored energy, storage duration and charging durations are made. For instance, utilization of stored energy could be to feed the grid, distribution companies or to power load system. These factors have great influence on the technical aspects of a proposed system. For instance, the adopted mode of operation could signal whether a single penstock or double penstock is appropriate for the system. Single penstocks require a pump-turbine while double penstocks can use a separate pumps and turbines.

Technical specification and components sizing is another main sub-activity for consideration within the required techno-economic framework. To analyse the P-HS technology, the knowledge of hydrodynamics is required for appropriate sizing of the system. In this regard, hydropower knowledge becomes useful with some consideration of P-HS uniqueness. Such considerations could include the horizontal and the vertical distance (head) between the two reservoirs, the flow rate of the turbine and pump, turbine and pump efficiency, the hydraulic control, water hammer effect etc. Also, suitable components for the system will need to be determined based on the site parameters and energy demand. Such as, the determination of penstock length, turbine type, the capacity of the turbine, the capacity of pumps etc. based on the head, flow rate, hydraulic radius, and velocity of flow and inner diameter of penstock.

The knowledge of fluid mechanics and hydrodynamics engineering aids in the sizing of the system and consequently the economic analysis which is important to justify P-HS investment. A good investment requires the demonstration of its viability and the possibility to recoup the capital with profit. Thus, to develop a P-HS system that competes in the energy market, the economic viability has to be proven. The investment must show evidence of a reasonable return and payback period using basic engineering economic principles which includes the time value of money, inflationary factors, future price reduction etc. Economic models such as Simple payback period, Energy Return on Investment (EROI), Levelised Cost of Energy, Lifecycle cost analysis etc. could be adapted for this purpose and to benchmark the cost at which the storage system is economically viable.

Energy plans and policies are meant to guide the development and operation of energy infrastructures. Plans and policies regarding adoption of new energy generation systems, its developments and better management are mostly communicated in Nigeria through various directives and communiqués from the power sector. The content of this documents do contain both the will and power to act on new technologies. However, Adhekpukoli (2018) noticed that the existing policies towards renewable energy are not enough to stimulate individual interest. In that light, there is also the need to extend the energy plans and policies to P-HS. This can be achieved by considering the recommendation of Oyedepo et al. (2018) for a regular evaluation of existing energy policy and plans. Of course, the policies should also include the creation of a profitable environment to attract energy investors. Furthermore, the incorporation of P-HS plans into the medium and long term plans and creation of cost-reflective tariffs could encourage investment. This is really required to accelerate the pace of P-HS adoption.

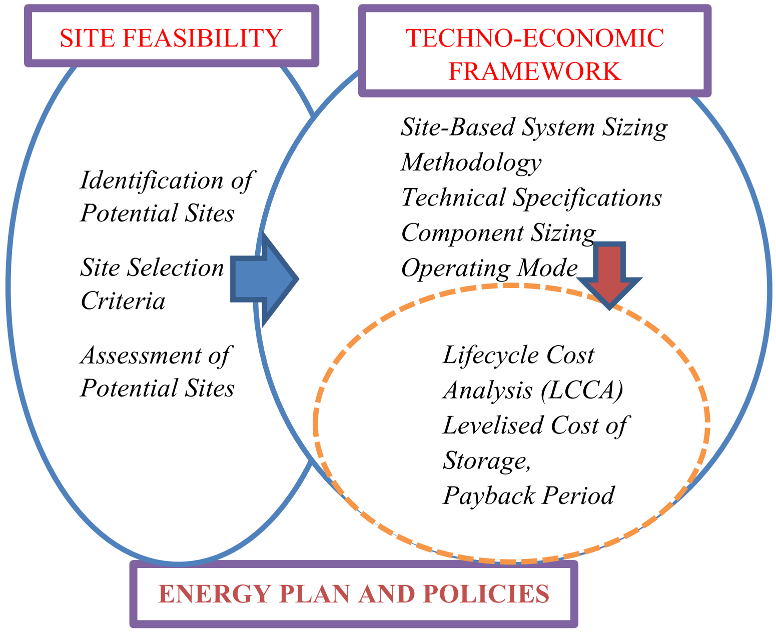

Figure 2: Conceptual Framework towards the Application of P-HS in Nigeria (Author's Concept)

6. Implications of Applying Pumped-Hydro Storage in Nigeria

The potential ways in which the application of pumped hydro storage would benefit the Nigerian power sector are now explained.

6.1 Electric Power Supply

It is obvious that electricity in Nigeria today is characterised by low generation capacity and the way to keep pace is through the development of more generation plants. In this regard, P-HS has a lot of potential to increase the power generation capacity in Nigeria for both rural and urban areas. Considering that Nigeria has adequate resource to support the technology, appropriate steps towards its development would help harness the resources effectively. P-HS has the capacity to generate energy at any scale and its technical characteristics such as long life (30-60 year), low cycle cost and moderate efficiency (Ayodele and Ogunjuyigbe 2015; Akinyele and Akuru 2014) grants it advantages over other storage technologies. Thus, it can help trigger monumental energy generation across the country simultaneously.

Also, P-HS has the capacity to form an integrated system with many renewable energy sources for adequate power supply. The intermittency of renewable energy generation and the time specificity problem can be mitigated through a storage technology. In this regard, P-HS represents an effective storage scheme that supports many renewable energy sources. P-HS has a matured technology and its capability cuts across small, medium and large scale energy storage (Guney and Tepe 2017).

6.2 Decentralisation of Energy Management

Aside from the problem of poor generation that has bedevilled the Nigerian power sector; the management of the entire value chain has not been effective. Electricity management in Nigeria is majorly centralised with a larger percentage of the generated power being fed into the grid. Meanwhile, not all the population are connected to the grid system. The grid itself is an ageing facility that is inefficiently operated, poorly managed and often experience frequent collapse due to its low reliability. For instance in 2016 alone, the grid collapsed up to six times (Lawal and Ojo 2017) consequently affecting economy activities (Tvaronavičienė et al. 2017; Cucchiella et al. 2018). By adopting P-HS, grid stabilisation and energy efficiency can be achieved. Also, P-HS could help the process of decentralising the energy system by offering support to the development of micro grids, standalone generation and distributed energy generation which could lessen the burden of the national grid and at the same time eliminate management and operational complexities.

6.3 Ancillary Services

Ancillary services are functions of the grid that involves the continuous matching of electricity supply and demand. The service goes beyond the basic generation and transmission of electricity to cover various activities that help to maintain electricity stability and security. This is an aspect that is deficient in the Nigerian power sector. The series of mismatch between supply and demand have caused a lot of havoc in Nigeria energy system. This distress can be reduced by using P-HS to remove the imbalance in the energy supply and demand.

Also, with the current unbundling in power sector of Nigeria, P-HS can support arbitrage services to encourage more public and private investment in power sector. Arbitrage service involves trading (i.e. buying and selling) of energy to take advantage of periods when electricity prices are low and to resell for profit when the price is high. This practice is globally acceptable and P-HS operation can be deployed in such direction to help the nation's power sector to become more attractive.

6.4 Global Warming and Climate Change Control

The use of fossil fuels for energy generation and other activities has been identified as one of the contributing factors to the increasing global warming and climate change in the world today (IPCC 2001; Sarah 2002; Oyedepo 2012). Oyedepo et al. (2018) noticed non-renewable energy sources as the major power generation of the world in the present day. This is the same for the Nigerian power sector where electricity generation is currently fossil fuel dependent as a result of its abundance in the country. However, with the increase in global warming, climate change, excessive rain and consequent flooding, substitution of renewable energy sources for non-renewables has been identified as a possible way to lessen these effects (Lu et al. 2017; Adebimpe et al. 2020). In the light of this, P-HS represent a renewable energy source that can help reduce the adverse effect of emission as well as provide a good viable storage for other renewable energy sources.

7. Conclusions

Solving energy issue in Nigeria is central to economic growth and improved standard of living. This study has presented P-HS as one of the potent energy systems that can bring relief to the present power situation in Nigeria. The study established a conceptual framework towards the application of P-HS and showed the key themes required for its achievement in Nigeria. The sub activities within each theme, the developmental process and the influence were revealed. Further, the work considered ways in which pumped-hydro storage technology would benefit the Nigerian power sector. These include areas such as energy supply, energy management, global warming and their environmental impacts. It was perceived that this technology can bring a positive turn around to the power sector. Therefore, taking decisive actions towards the technology would be a way of unlocking its full potentials.

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